Estuarine Management and Technologies Journal

Estuarine Management and Technologies 3: 113–121 (2026)
DOI: 10.3897/emt.3.183953

Mini-Review

Review on plastic-derived chemical pollutants in estuarine ecosystems: Assessing the scale of microplastic contamination

A. R. Nisari[1], K. R. Renjith[1]

1 *Ecology and Environment Research Group, KSCSTE- Centre for Water Resources Development and Management (CWRDM), Kozhikode-673571, Kerala, India*
Corresponding author: K. R. Renjith (renjith@cwrdm.org)

Abstract

The major source of synthetic additives in estuarine ecology is plastic contamination and its dispersion. Therefore, the plastic-related chemicals can be used as an indicator of microplastic pollution in various environmental niches. The persistence and accumulation characteristics of these chemicals enhance their transfer to water, sediment, and biotic materials. These chemicals are endocrine disruptors and mutagens that affect the next generation. Systematic scientific approaches are essential for the remedial measures and sustainable environmental management processes.

Graphical Abstract

Key words: Microplastics, plastic, plastic additives

OPEN ACCESS

This article is part of:
Microplastic and Nanoplastic Pollution in Different Environments: Freshwater and Marine Perspectives
Edited by Dr. Balaji Prasath Barathan

Academic editor:
Balaji Prasath Barathan
Received: 31 December 2025
Accepted: 13 March 2026
Published: 25 March 2026

Citation: Nisari AR, Renjith KR (2026) Review on plastic-derived chemical pollutants in estuarine ecosystems: Assessing the scale of microplastic contamination. Estuarine Management and Technologies 3: 113–121. https://doi.org/10.3897/emt.3.183953

Copyright: © A. R. Nisari & K. R. Renjith. This is an open access article distributed under terms of the Creative Commons Attribution License (Attribution 4.0 International – CC BY 4.0).

Introduction

The projectile propagation of global plastic production demonstrates the multiple utilization characteristics of both thermoplastics and thermosets. The malleability and persistence of these man-made materials render them a convenient product and a permanent contaminant in the ecosystem concurrently. Reviews indicate that it is one of the predominant pollutants currently arising from a bulk polymer manufacturing in the 20th century (Geyer et al. 2017; Lim 2021; Jadhav et al. 2023). Alarmingly, about 60% of all plastics ever produced are discarded, primarily due to their limited recyclability and inadequate waste management (Leonova et al. 2022). The major mechanisms contributing to the origin of the microplastics include photo-oxidation, physical abrasion, climatic changes, chemical reactions, and biological interactions. The weathering, adherence to the biome, and dispersion of by-products are the most pressing environmental challenges interrelated with microplastic fragmentation (Chamas et al. 2020). Covalently bonded various toxic chemicals in plastic are gradually released into the surroundings through the same processes simultaneously. The migration of these micro particles and additives across trophic levels induces genetic disorders, prenatal effects, and impaired cognitive functions (Zhang et al. 2021). The present mini-review investigation focused on the relations between plastic additives and the microplastic origin from the plastic dispersion process. The major keywords taken for the Science Direct and Google Scholar analysis were “plastic”, “microplastic”, and “additives”.

Emergence of microplastics (MPs) as a contaminant of concern

Various abiotic and biotic processes generate significant amounts of small plastic debris and their constituents in the environment at the micro level (<0.5 mm) (Thompson et al. 2004; Dawson et al. 2018; Suzuki et al. 2024). The purposely manufactured primary and exfoliated secondary microplastics ultimately end up in different environmental compartments. The microscopic classification and confirmation using spectroscopic techniques are important steps in the separation and identification of man-made microcontaminants. The two major types of microplastic toxicity induction arise as a vector of hazardous chemicals and secondly, as an intrinsic pollution source (Dai et al. 2024). The synergistic toxicity level is increased by the interaction of pesticides, pharmaceuticals, and trace metals (Deng et al. 2020; Mammo et al. 2020; Pandey et al. 2021). The plastic additives are easily detached under various atmospheric conditions and migrate through food chains. These smaller molecules with a low boiling point have always transported faster between phases through chemisorption and physisorption mechanisms. The polymer character, additive content, environmental factors, and the size and shape of microplastics correlated with the quantity and kinetics (Cheng et al. 2024). Particle diffusion and aqueous boundary layer diffusion models have recently been demonstrated in advanced research methodologies of these additives. The correlating effects of microplastics and additives in a controlled laboratory setting are described in the literature, and the changing environmental context requires further investigation (da Costa et al. 2024; Fricano et al. 2025). The ubiquitous nature of microplastic additives has been documented across multiple freshwater (Mintenig et al. 2020), estuaries (Pabortsava and Lampitt 2020; Wang et al. 2020), drinking water (Zhang et al. 2020), and terrestrial ecosystems (Zhou et al. 2021). These studies were reported related to microbial activities, adsorption dynamics, desorption processes, polymer degradation, film formation, and toxicity interactions. The ocean is recognized as a major repository for microplastics, with estimates suggesting tons are floating on the surface of the global oceans (Eriksen et al. 2014). These plastic contaminants in low-lying aquatic systems are affected by the tidal effects, salinity gradients, acidic content, chlorophyll concentrations, and biotic interactions. Filling the knowledge gap in the influencing factors and the chemical kinetics will be a next step to the degradation and management strategies. A comparison table of microplastic concentrations in various regions is presented in Table 1. The variation in the total abundance of microplastics from different regions of the globe can be distinguished.

Plastic-derived chemicals in the estuarine ecosystem

Estuaries, the dynamic transitional ecosystems where freshwater and marine environments converge, hold paramount importance in global biogeochemical cycles and ecological processes (Wen et al. 2023). The proximity of these systems to riverine inflow, mangrove debris, coastal influx, urban runoff, and anthropogenic activities makes them highly productive and depositional environments in tropical regions (Prasad et al. 2024). The plastic additives in different aquatic ecosystems are described in Table 2. Different additive groups,

Table 1. Distribution of microplastics in different regions studied across the globe.

Study area	Microplastic	Average abundance	References
Changjiang Estuary, China	Surface water	23.1 ± 18.2 n/100 L.	Xu et al. 2018
Qinzhou Bay, China	Sediment	15 to 12,852 Items kg/L	Li et al. 2018
Douro estuary	Fish larvae	1 fish larva: 1.5 microplastics	Rodrigues et al. 2019
Poyang Lake	Water	5.34 Items/L	Yuan et al. 2019
Hangzhou Bay	Agricultural soil	503.3 Pieces kg/L	Zhou et al. 2020
Pearl River Estuary	Sediment	851 ± 177 Items/Kg	Zuo et al. 2020
Klang River Estuary	Sediment	0.5 to 4.5 Particles/L	Zaki et al. 2021
Dongshan Bay of China	Sediment	0.23 to 4.01 particles m−3	Pan et al. 2021
Beaches, South West Coast of India	Beach sediments	370 to 708 Particles/Kg	Kaviarasan et al. 2022
Kallar Kahar wetland, Pakistan	Sediment	5720 ± 2580 Items/Kg	Dilshad et al. 2022
River-dominated estuary, Bangladesh	Sediment	3.65 to 4.33 Items per m^3	Rakib et al. 2023
Tamar River, England	Water	0.04 to 0.99 microplastics/m3	Sullivan et al. 2023
Azhikkal estuary, Arabian Sea	Sediment	1260 Particles/Kg	Sunil et al. 2024
Yangtze River estuary	Sediment	1.01 (± 0.65) n m−3	Wu et al. 2024
Sundarbans mangrove	Surface water	4.66–58.33 MPs/L	Saini et al. 2025
Ashtamudi estuary, India	Surface water	3.2 to 53 items/L	Priya et al. 2025

including Benzotriazole UV stabilizers (BUVSs), Phthalates, benzophenone, bisphenol, and alkylphenols, polybrominated diphenyl ethers (PBDEs), Tris (butoxy ethyl) phosphate, and organophosphate esters, have been documented in diverse coastal systems. The sediments are the most important sink of organic and inorganic depository pools (Zhang et al. 2019; Zhao et al. 2019). They serve as the ultimate repository for organic carbon, inorganic particles, and synthetic materials, facilitating the integration of organic matter into the geological carbon cycle (Dickens 2021). When several physical, chemical, and biological processes combine, a substantial number of external synthetic materials sink through the water column and are eventually retained in sediments (Hu et al. 2018; Liu et al. 2022). Particles that settle in bed sediment possess distinctive biochemical composition and characteristics. The amount fluctuates depending on production patterns, transportation, and environmental factors (Bergmann et al. 2019; Dai et al. 2024). Because the majority of the world's population resides close to coastal areas (Cole et al. 2011), they are particularly vulnerable. Plastic chemicals are used in the manufacturing process to enhance properties such as elasticity, binding capacity, flame retardancy, stability, and other polymer properties. The chemical composition of additives affects entire estuarine sedimentation rates, water mass dynamics, redox potential, salinity gradients, tidal fluctuations, food availability, and productivity (Mathalon and Hill 2014; Yu et al. 2016; da Costa Araújo et al. 2020; Mehdinia et al. 2020). However, the growing pollution in these aquatic habitats with non-degradable chemical debris is one of the major subjects due to its persistent nature to sink and settle in these sensitive ecosystems. The impact of individual parametric effects needs to be evaluated, and a conceptual framework for analysis should be standardized. In estuarine aquatic habitats, MPs have directly affected the resident fish and other aquatic-dwelling organisms. The fragmented MPs and additives in these intertidal ecosystems interfere with water availability, sediment characteristics, benthos survival rates, and fish health (Wright et al. 2013;

Auta et al. 2017). The sinking capacity in the aquaculture system, changes in biotic metabolism, pore water dynamics, habitat destruction, productivity reduction, and mutation require further elaborate investigation. Climatic variations, interactive reactions, standard procedures, degradation mechanisms of macro-plastics, and assessment protocols of nano-plastic particles are major recent topics for discussion in the global scientific community.

Table 2. Distribution of Plastic chemicals in different ecosystems worldwide.

Study area	Plastic chemicals	References
Marine products	Benzotriazole UV stabilizers (BUVSs)	Rani et al. 2015
River water	Phthalates, benzophenone, bisphenol, and alkylphenols	Bolívar-Subirats et al. 2020
Yangtze estuary	Phthalates (PAEs) and polybrominated diphenyl ethers (PBDEs)	Deng et al. 2021
Pearl River Delta	Phthalate esters (PAEs)	Cao et al. 2022
Nanyang Lake estuary	Tris (butoxy ethyl) phosphate	Sha et al. 2023
Benthic compartments from the Loire estuary	Organophosphate ester	Castro-Jiménez et al. 2024
Bay of Bengal Coastal Waters	Phenolic compounds	Chandran et al. 2025

Conclusion

Estuaries serve as a dynamic, transitional, and unique environment between the marine and freshwater environments. Plastic pollution and accumulation in the environment have both significantly increased over the past few decades. The physico-chemical aging process of plastic enhances the separation of microplastics and additives. However, the growing pollution in these aquatic habitats with non-degradable organic debris is one of the major subject matters due to its persistent nature to sink and settle in these sensitive ecosystems. These combined microplastic and plastic chemical productions can be used as an ecological contamination marker in this ecosystem. It is essential to include long-term environmental monitoring on the interaction between microplastics and plastic additives in future research plans. Effective policy implementation and new law regulations are essential for sustainable development practices.

Acknowledgements

The authors acknowledge the Plan-funded project of the Kerala State Council for Science, Technology, and Environment (KSCSTE)- Centre for Water Resources Development and Management (CWRDM) titled “Occurrence, Ecotoxicological Risk and Correlation of Phthalate Esters with Potential Microplastic Contamination in Muvattupuzha River (PP-. 112/24).

Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

Use of AI

No use of AI was reported.

Funding

The Plan-fund of the Kerala State Council for Science, Technology, and Environment (KSCSTE), Government of Kerala.

Author contributions

ARN – Original Manuscript Drafting, Literature review, Data Comilation. KRR – Manuscript Editing, Project Supervision, Critical Revisions.

Author ORCIDs

K. R. Renjith https://orcid.org/0000-0002-1626-4479

Data availability

All of the data that support the findings of this study are available in the main text.

References

Auta HS, Emenike CU, Fauziah SH (2017) Screening of Bacillus strains isolated from mangrove ecosystems in Peninsular Malaysia for microplastic degradation. Environmental Pollution 231: 1552–1559. https://doi.org/10.1016/j.envpol.2017.09.043

Bergmann M, Mützel S, Primpke S, Tekman MB, Trachsel J, Gerdts G (2019) White and wonderful? Microplastics prevail in snow from the Alps to the Arctic. Science Advances 5(8): eaax1157. https://doi.org/10.1126/sciadv.aax1157

Bolívar-Subirats G, Cortina-Puig M, Lacorte S (2020) Multiresidue method for the determination of high production volume plastic additives in river waters. Environmental Science and Pollution Research 27(33): 41314–41325. https://doi.org/10.1007/s11356-020-10118-2

Cao Y, Lin H, Wang Q, Li J, Liu M, Zhang K, Xu S, Huang G, Ruan Y, Wu J, Leung KMY, Lam PK (2022) Significant riverine inputs of typical plastic additives-phthalate esters from the Pearl River Delta to the northern South China Sea. Science of the Total Environment 849: 157744. https://doi.org/10.1016/j.scitotenv.2022.157744

Castro-Jiménez J, Aminot Y, Bely N, Pollono C, Idjaton BI T, Bizzozero L, Pierre-Duplessix O, Phuong NN, Gasperi J (2024) Organophosphate ester additives and microplastics in benthic compartments from the Loire estuary (French Atlantic coast). Marine Pollution Bulletin 201: 116256. https://doi.org/10.1016/j.marpolbul.2024.116256

Chamas A, Moon H, Zheng J, Qiu Y, Tabassum T, Jang JH, Abu-Omar M, Scott SL, Suh S (2020) Degradation rates of plastics in the environment. ACS Sustainable Chemistry & Engineering 8(9): 3494–3511. https://doi.org/10.1021/acssuschemeng.9b06635

Chandran GR, Elaiyaraja A, Menon AM, Bommuraj V, Santhanam P, Rajendran RB (2025) Endocrine disrupting phenolic plasticizers in the Bay of Bengal coastal waters, India: Occurrence, Distribution and Environmental Risk Assessment. Environmental Pollution 127307. https://doi.org/10.1016/j.envpol.2025.127307

Cheng Y, Guo Y, Wang F, Zhang L (2024) Effects of polyethylene microplastics stress on soil physicochemical properties mediated by earthworm *Eisenia fetida*. Environmental Science and Pollution Research 31(8): 12071–12082. https://doi.org/10.1007/s11356-024-32007-8

Cole M, Lindeque P, Halsband C, Galloway TS (2011) Microplastics as contaminants in the marine environment: a review. Marine Pollution Bulletin 62(12): 2588–2597. https://doi.org/10.1016/j.marpolbul.2011.09.025

da Costa Araújo AP, Gomes AR, Malafaia G (2020) Hepatotoxicity of pristine polyethylene microplastics in neotropical *Physalaemus cuvieri* tadpoles (Fitzinger, 1826). Journal of Hazardous Materials 386: 121992. https://doi.org/10.1016/j.jhazmat.2019.121992

da Costa JP, Avellan A, Tubić A, Duarte AC, Rocha-Santos T (2024) Understanding interface exchanges for assessing environmental sorption of additives from microplastics: current knowledge and perspectives. Molecules 29(2): 333. https://doi.org/10.3390/molecules29020333

Dai C, Yuan F, Wang D, Yang X, Du J, Yu W, Zhang C (2024) Settling velocity of submillimeter microplastic fibers in still water. Science of the Total Environment 907: 168054. https://doi.org/10.1016/j.scitotenv.2023.168054

Dawson AL, Kawaguchi S, King CK, Townsend KA, King R, Huston WM, Bengtson Nash SM (2018) Turning microplastics into nanoplastics through digestive fragmentation by Antarctic krill. Nature Communications 9(1): 1001. https://doi.org/10.1038/s41467-018-03465-9

Deng H, Li R, Yan B, Li B, Chen Q, Hu H, Xu Y, Shi H (2021) PAEs and PBDEs in plastic fragments and wetland sediments in Yangtze estuary. Journal of Hazardous Materials 409: 124937. https://doi.org/10.1016/j.jhazmat.2020.124937

Deng L, Cai L, Sun F, Li G, Che Y (2020) Public attitudes towards microplastics: Perceptions, behaviors and policy implications. Resources, Conservation and Recycling 163: 105096. https://doi.org/10.1016/j.resconrec.2020.105096

Dickens J (2021) Of Mysid and Menidia: Sublethal Effects of Micro and Nanoplastics on Estuarine Indicator Species.

Dilshad A, Taneez M, Younas F, Jabeen A, Rafiq MT, Fatimah H (2022) Microplastic pollution in the surface water and sediments from Kallar Kahar wetland, Pakistan: occurrence, distribution, and characterization by ATR-FTIR. Environmental Monitoring and Assessment 194(7): 511. https://doi.org/10.1007/s10661-022-10171-z

Eriksen M, Lebreton LC, Carson HS, Thiel M, Moore CJ, Borerro JC, Galgani F, Ryan PG, Reisser J (2014) Plastic pollution in the world's oceans: more than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea. PLOS ONE 9(12): e111913. https://doi.org/10.1371/journal.pone.0111913

Fricano A, Bianchi F, Di Filippo P, Pomata D, Riccardi C, Simonetti G, Buiarelli F (2025) Determination of additives as markers of microplastic contamination in the environment. Talanta 285: 127344. https://doi.org/10.1016/j.talanta.2024.127344

Geyer R, Jambeck JR, Law KL (2017) Production, use, and fate of all plastics ever made. Science Advances 3(7): e1700782. https://doi.org/10.1126/sciadv.1700782

Hu L, Chernick M, Hinton DE, Shi H (2018) Microplastics in small waterbodies and tadpoles from Yangtze River Delta, China. Environmental Science & Technology 52(15): 8885–8893. https://doi.org/10.1021/acs.est.8b02279

Jadhav HS, Fulke AB, Jablonski MR, Giripunje MD (2023) Microplastic Pollution in Marine Ecosystem and Its Remediation. In: Current Status of Marine Water Microbiology. Singapore: Springer Nature Singapore, 279–296. https://doi.org/10.1007/978-981-99-5022-5_12

Kaviarasan T, Dhineka K, Sambandam M, Sivadas SK, Sivyer D, Hoehn D, Pradhan U, Mishra P, Murthy MR (2022) Impact of multiple beach activities on litter and microplastic composition, distribution, and characterization along the southeast coast of

India. Ocean & Coastal Management 223: 106177. https://doi.org/10.1016/j.ocecoaman.2022.106177

Leonova N, Loboichenko V, Divizinyuk M, Shevchenko R (2022) Study of short-term effects on the soil of disposable protective face masks used in the COVID-19 pandemic. Key Engineering Materials 925: 197–210. https://doi.org/10.4028/p-zjo35h

Li J, Zhang H, Zhang K, Yang R, Li R, Li Y (2018) Characterization, source, and retention of microplastic in sandy beaches and mangrove wetlands of the Qinzhou Bay, China. Marine Pollution Bulletin 136: 401–406. https://doi.org/10.1016/j.marpolbul.2018.09.025

Lim X (2021) Microplastics are everywhere—but are they harmful. Nature 593(7857): 22–25. https://doi.org/10.1038/d41586-021-01143-3

Liu X, Liu H, Chen L, Wang X (2022) Ecological interception effect of mangroves on microplastics. Journal of Hazardous Materials 423: 127231. https://doi.org/10.1016/j.jhazmat.2021.127231

Mammo FK, Amoah ID, Gani KM, Pillay L, Ratha SK, Bux F, Kumari S (2020) Microplastics in the environment: Interactions with microbes and chemical contaminants. Science of the Total Environment 743: 140518. https://doi.org/10.1016/j.scitotenv.2020.140518

Mathalon A, Hill P (2014) Microplastic fibers in the intertidal ecosystem surrounding Halifax Harbor, Nova Scotia. Marine Pollution Bulletin 81(1): 69–79. https://doi.org/10.1016/j.marpolbul.2014.02.018

Mehdinia A, Dehbandi R, Hamzehpour A, Rahnama R (2020) Identification of microplastics in the sediments of southern coasts of the Caspian Sea, north of Iran. Environmental Pollution 258: 113738. https://doi.org/10.1016/j.envpol.2019.113738

Mintenig SM, Kooi M, Erich MW, Primpke S, Redondo-Hasselerharm PE, Dekker SC, Koelmans AA, Van Wezel AP (2020) A systems approach to understand microplastic occurrence and variability in Dutch riverine surface waters. Water Research 176: 115723. https://doi.org/10.1016/j.watres.2020.115723

Pabortsava K, Lampitt RS (2020) High concentrations of plastic hidden beneath the surface of the Atlantic Ocean. Nature Communications 11(1): 4073. https://doi.org/10.1038/s41467-020-17932-9

Pan Z, Liu Q, Jiang R, Li W, Sun X, Lin H, Jiang S, Huang H (2021) Microplastic pollution and ecological risk assessment in an estuarine environment: The Dongshan Bay of China. Chemosphere 262: 127876. https://doi.org/10.1016/j.chemosphere.2020.127876

Prasad S, Dinesh GK, Sinduja M, Sathya V, Poornima R, Karthika S [Eds] (2024) The Role of Microbes and Microbiomes in Ecosystem Restoration (Vol. 1). Bentham Science Publishers. https://doi.org/10.2174/9789815256598124010 1

Priya KL, Azhikodan G, Yokoyama K, Renjith KR (2025) Analysing the influence of hydrodynamic and sedimentary factors on the microplastic distribution in the Ashtamudi estuary, India. Marine Pollution Bulletin 212: 117537. https://doi.org/10.1016/j.marpolbul.2025.117537

Pandey D, Singh A, Ramanathan A, Kumar M (2021) The combined exposure of microplastics and toxic contaminants in the floodplains of north India: A review. Journal of Environmental Management 279: 111557. https://doi.org/10.1016/j.jenvman.2020.111557

Rakib MR J, Al Nahian S, Madadi R, Haider SM B, De-la-Torre GE, Walker TR, Jonathan MP, Cowger W, Khandaker MU, Idris AM (2023) Spatiotemporal trends and characteristics of microplastic contamination in a large river-dominated estuary. Environmental Science: Processes & Impacts 25(5): 929–940. https://doi.org/10.1039/d3em00014a

Rani M, Shim WJ, Han GM, Jang M, Al-Odaini NA, Song YK, Hong SH (2015) Qualitative analysis of additives in plastic marine debris and its new products. Archives of Environmental Contamination and Toxicology 69(3): 352–366. https://doi.org/10.1007/s00244-015-0224-x

Rodrigues SM, Almeida CM R, Silva D, Cunha J, Antunes C, Freitas V, Ramos S (2019) Microplastic contamination in an urban estuary: abundance and distribution of microplastics and fish larvae in the Douro estuary. Science of the Total Environment 659: 1071–1081. https://doi.org/10.1016/j.scitotenv.2018.12.273

Saini N, Ghosh A, Bhadury P (2025) Linking plastic degradation potential and resistance gene abundance in bacterioplankton community of the Sundarbans estuarine ecosystem. FEMS Microbiology Letters 372: fnaf067. https://doi.org/10.1093/femsle/fnaf067

Sha W, Wang Y, Cai F, Zhang C, Wang C, Chen J, Liu C, Wang R, Gao P (2023) Regional distribution of the plastic additive tris (butoxyethyl) phosphate in Nanyang Lake estuary, China, and toxic effects on *Cyprinus carpio*. Environmental Science and Pollution Research 30(18): 53566–53576. https://doi.org/10.1007/s11356-023-26168-1

Sunil M, Mithun N, Kalthur G, Nair MP, Gopinath A, Chidangil S, Kumar S, Lukose J (2024) Analysis of microplastics in the estuary lying along the coastal belt of the Arabian Sea. Case Studies in Chemical and Environmental Engineering 10: 100804. https://doi.org/10.1016/j.cscee.2024.100804

Sullivan E, Cole M, Atwood EC, Lindeque PK, Chin PT, Martinez-Vicente V (2023) *In situ* correlation between microplastic and suspended particulate matter concentrations in river-estuary systems support proxies for satellite-derived estimates of microplastic flux. Marine Pollution Bulletin 196: 115529. https://doi.org/10.1016/j.marpolbul.2023.115529

Suzuki G, Uchida N, Tanaka K, Higashi O, Takahashi Y, Kuramochi H, Yamaguchi N, Osako M (2024) Global discharge of microplastics from mechanical recycling of plastic waste. Environmental Pollution 348: 123855. https://doi.org/10.1016/j.envpol.2024.123855

Thompson RC, Olsen Y, Mitchell RP, Davis A, Rowland SJ, John AW, McGonigle D, Russell AE (2004) Lost at sea: where is all the plastic? Science 304(5672): 838–838. https://doi.org/10.1126/science.1094559

Wang F, Gao J, Zhai W, Liu D, Zhou Z, Wang P (2020) The influence of polyethylene microplastics on pesticide residue and degradation in the aquatic environment. Journal of Hazardous Materials 394: 122517. https://doi.org/10.1016/j.jhazmat.2020.122517

Wen Q, Liu N, Qu R, Ge F (2023) High salinity promotes the photoaging of polystyrene microplastics with humic acid in seawater. Science of the Total Environment 901: 165741. https://doi.org/10.1016/j.scitotenv.2023.165741

Wright SL, Rowe D, Thompson RC, Galloway TS (2013) Microplastic ingestion decreases energy reserves in marine worms. Current Biology 23(23): R1031–R1033. https://doi.org/10.1016/j.cub.2013.10.068

Wu P, Fan Y, Zhang X, Wu W, Zhang Z, Wu Y, Wang G, Chen T, Gao B (2024) Seasonal dynamics, tidal influences, and anthropogenic impacts on microplastic distribution in the Yangtze River estuary: A comprehensive characterization and comparative analysis. Journal of Hazardous Materials 476: 135167. https://doi.org/10.1016/j.jhazmat.2024.135167

Xu P, Peng G, Su L, Gao Y, Gao L, Li D (2018) Microplastic risk assessment in surface waters: A case study in the Changjiang Estuary, China. Marine Pollution Bulletin 133: 647–654. https://doi.org/10.1016/j.marpolbul.2018.06.020

Yu X, Peng J, Wang J, Wang K, Bao S (2016) Occurrence of microplastics in the beach sand of the Chinese inner sea: the Bohai Sea. Environmental Pollution 214: 722–730. https://doi.org/10.1016/j.envpol.2016.04.080

Yuan W, Liu X, Wang W, Di M, Wang J (2019) Microplastic abundance, distribution and composition in water, sediments, and wild fish from Poyang Lake, China. Ecotoxicology and Environmental Safety 170: 180–187. https://doi.org/10.1016/j.ecoenv.2018.11.126

Zaki MR M, Ying PX, Zainuddin AH, Razak MR, Aris AZ (2021) Occurrence, abundance, and distribution of microplastics pollution: an evidence in surface tropical water of Klang River estuary, Malaysia. Environmental Geochemistry and Health 43(9): 3733–3748. https://doi.org/10.1007/s10653-021-00872-8

Zhang D, Liu X, Huang W, Li J, Wang C, Zhang D, Zhang C (2020) Microplastic pollution in deep-sea sediments and organisms of the Western Pacific Ocean. Environmental Pollution 259: 113948. https://doi.org/10.1016/j.envpol.2020.113948

Zhang J, Zhang C, Deng Y, Wang R, Ma E, Wang J, Bai J, Wu J, Zhou Y (2019) Microplastics in the surface water of small-scale estuaries in Shanghai. Marine Pollution Bulletin 149: 110569. https://doi.org/10.1016/j.marpolbul.2019.110569

Zhang Y, Gao T, Kang S, Allen S, Luo X, Allen D (2021) Microplastics in glaciers of the Tibetan Plateau: Evidence for the long-range transport of microplastics. Science of the Total Environment 758: 143634. https://doi.org/10.1016/j.scitotenv.2020.143634

Zhao S, Wang T, Zhu L, Xu P, Wang X, Gao L, Li D (2019) Analysis of suspended microplastics in the Changjiang Estuary: Implications for riverine plastic load to the ocean. Water Research 161: 560–569. https://doi.org/10.1016/j.watres.2019.06.019

Zhou B, Wang J, Zhang H, Shi H, Fei Y, Huang S, Tang Y, Wen D, Luo Y, Barceló D (2020) Microplastics in agricultural soils on the coastal plain of Hangzhou Bay, east China: Multiple sources other than plastic mulching film. Journal of Hazardous Materials 388: 121814. https://doi.org/10.1016/j.jhazmat.2019.121814

Zhou Y, He G, Jiang X, Yao L, Ouyang L, Liu X, Liu W, Liu Y (2021) Microplastic contamination is ubiquitous in riparian soils and strongly related to elevation, precipitation and population density. Journal of Hazardous Materials 411: 125178. https://doi.org/10.1016/j.jhazmat.2021.125178

Zuo L, Sun Y, Li H, Hu Y, Lin L, Peng J, Xu X (2020) Microplastics in mangrove sediments of the Pearl River Estuary, South China: Correlation with halogenated flame retardants' levels. Science of the Total Environment 725: 138344. https://doi.org/10.1016/j.scitotenv.2020.138344